CHAPTER C.15
MODELING AND MONITORING

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15.1 Introduction

Management of disturbed ecosystems to hasten their regeneration is, in its simplest interpretation, the manipulation of ecological processes for a specific purpose. Ecological theory that pertains to ecosystem regeneration and development can be used to design more effective management programs that are less expensive, more quickly implemented, and provide more desirable results (Christensen *et al.* 1996). Although the most commonly employed criterion for judging the success of an ecosystem rehabilitation project is simply whether or not the reconstituted community resembles the original, in terms of the dominant species and physiognomy, such comparisons often prove deceptive when, in the longer term, the recreated community disintegrates. The effectiveness of ecosystem restoration should also be judged by other criteria including sustainability, productivity, nutrient retention and biotic interactions (Ewel 1987).

Management goals and protocols in rehabilitation programs should be viewed as hypotheses of routes to achieve clearly stated goals. Because the desired goals of rehabilitation projects are time-dependent (*i.e.*, long-term), ecological modeling is needed to assist in evaluating the success of restored sites by simulating more realistic end points. Models are useful in identifying attributes that provide a measure of the behavior of a broad suite of ecosystem properties and allow the selection of alternative courses of action during the rehabilitation project (Lee & Gosselink 1988; Mitsch 1994; Lee 1993). In addition, models represent an important "cross-fertilization" (Shugart 1989) between long-term ecological studies and ecological modeling. Development of interactive, spatially explicit models that allow the evaluation of simulated results of proposed management alternatives across the landscape are therefore strongly recommended (Meyer & Swank 1996). The introduction of a modeling component to a restoration program can help forecast the trajectories of success criteria in terms of structure and productivity, hydrology, recruitment, nutrient dynamics, and sustainability within a particular domain (e.g., ecophysiology, ecosystem energetics, community organization, landscape patterns). Modeling also can be used in adaptive management to modify or adjust restoration programs or actions, and to provide analysis and guidelines as to the efficiency of different rehabilitation strategies (Figure C.15-1). The identification of important research topics and monitoring criteria to improve the understanding of key ecological processes are also potential products of ecological modeling efforts when linked to monitoring programs in restoration projects.

Simulation models should be considered an integral tool in the selection of performance criteria in ecosystem restoration efforts. Such models can provide conceptual relevance by linking ecological attributes to specific mechanisms of system behavior – thus providing insights into the effectiveness of proposed restoration measures. Simulation models are constructed to emulate how multiple forcing functions, at appropriate temporal and spatial scales, control system behavior. The modeling process also decides what is the appropriate output to evaluate ecosystem change, and how to evaluate the statistical reliability of this output in defining the range of system response to ecological noise. This effort to construct effective models that simulate ecosystem behavior parallel many of the decision protocols used to select monitoring variables to evaluate restoration effectiveness.

Effective monitoring programs can benefit the process of simulation modeling by providing descriptions of system response (Figure C.15-1). This process is required to adequately test causal hypotheses of system degradation upon which restoration measures are designed. This feedback provides a strategic process in performing adaptive management and assessment. Sensitivity analyses during model development provide science programs insights as to what parameters may be most significant to system behavior. These exercises can also provide insights as to the most cost-effective monitoring variables to include in evaluating ecosystem response. Uncertainty in model simulations depends on the natural variability of the ecosystem, but also on the lack of knowledge in parameter and model development. Monitoring programs can help reduce this uncertainty in knowledge by providing data on those parameters that can improve simulation capabilities. This feedback improves simulation models and reduces scientific uncertainty in understanding causal mechanisms associated with system degradation (Figure C.15-1). The ability to predict how ecosystems will respond to prescribed changes in environmental settings will be much improved with the quantitative rigor of simulation model exercises as the initial stages of restoration planning. This process is critical since it contributes to develop ecological theory that can be immediately used in developing restoration strategies and link directly science and management.

15.2 Monitoring and Modeling Integration

A System-wide Assessment and Monitoring Plan (SWAMP) needs to be developed that incorporates existing monitoring efforts (to the extent possible) within a system-wide experimental design. The SWAMP should integrate monitoring of biological, chemical, physical, and climatological variables in four modules: wetlands, barrier islands, inshore waters and rivers, and near coastal waters (hypoxia). The variables monitored will include those necessary to assess performance measures, as identified through modeling efforts, and to document the long-term restoration of LCA ecosystems. The first of these modules, wetlands, was designed under the CWPPRA monitoring program. The Coast-wide Reference Monitoring System – *Wetlands* (CRMS – *Wetlands*, Steyer *et al.* 2003) describes linkages to project-specific and system-wide objectives, reference site issues, statistical design, monitoring variables, sampling design, and implementation criteria. The CRMS-*Wetlands* monitoring program is compatible with the conceptual framework utilized in the LCA modeling effort. This framework was reviewed by the LCA modeling team and is currently being used as a template for inshore waters and rivers. Integration of monitoring efforts to support refinement of ecological, hydrodynamic, and water quality models as well as restoration assessment is key to the successful development of SWAMP (Figure C.15-2). The data gathered under CRMS-*Wetlands* and the other SWAMP modules will provide the robust datasets needed to improve the parameter quality and reduce the uncertainty associated with model development.

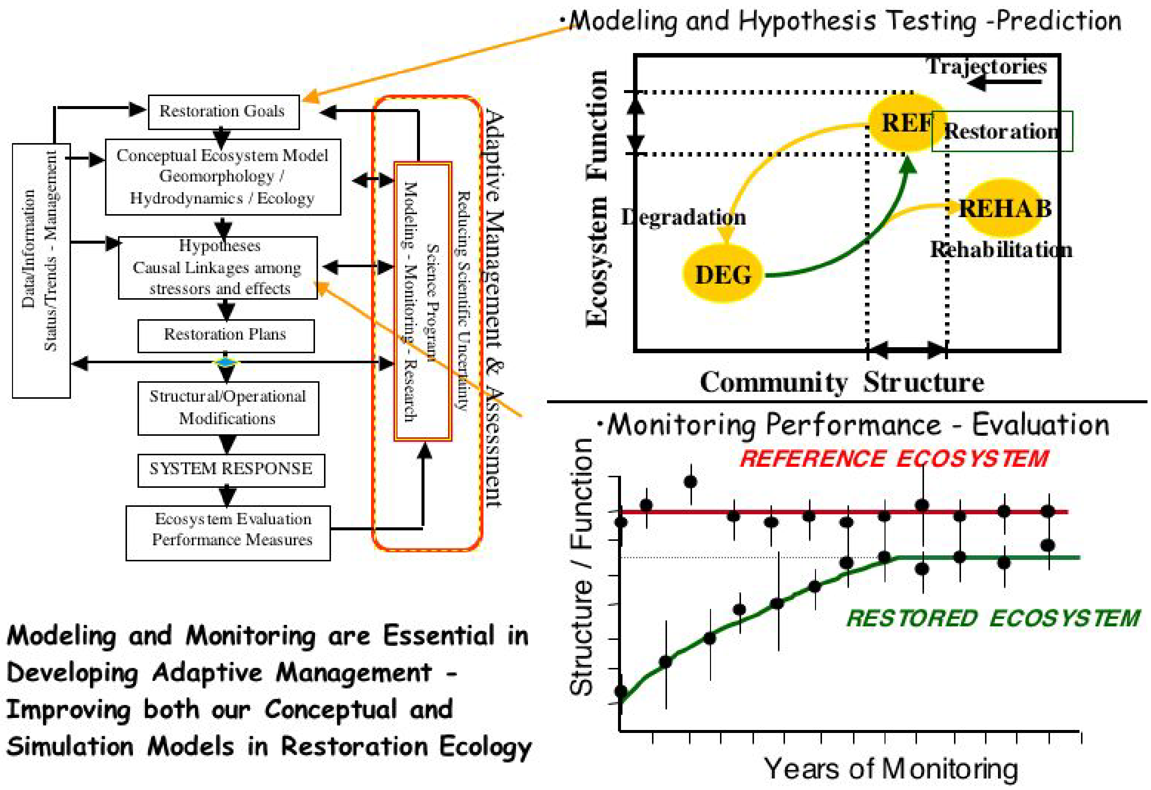

Figure C.15-1 Linkage of modeling and monitoring programs to develop adaptive management and assessment of restoration planning and evaluation

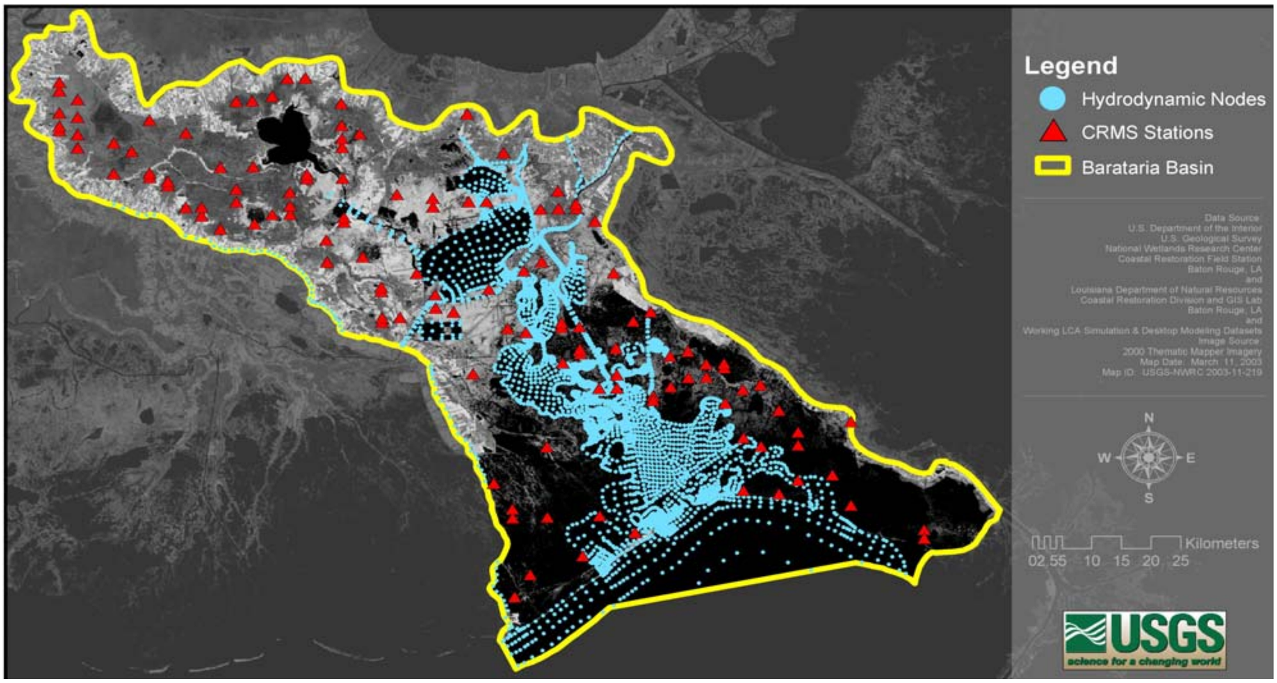

Figure C.15-2 Spatial Orientation of CRMS-Wetland Stations